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## The activity and rotation limit in the Hyades

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**Abstract.** We conduct a study of K to M type stars to investigate the activity and the rotation limit in the Hyades. We use a sample of 40 stars in this intermediate-age cluster ( $\approx 625$  Myr) to probe stellar rotation in the threshold region where stellar activity becomes prevalent. Here we present projected equatorial velocities ( $v_{\text{rot}} \sin i$ ) and chromospheric activity measurements ( $H_\alpha$ ) that indicate the existence of fast rotators in the Hyades at spectral types where also the fraction of stars with  $H_\alpha$  emission shows a rapid increase (“ $H_\alpha$  limit”). The locus of enhanced rotation (and activity) thus seems to be shifted to earlier types in contrast to what is seen as the rotation limit in field stars. The relation between activity and rotation appears to be similar to the one observed in fields stars.

### 1. Introduction

Solar-type stars are mostly fast rotators and magnetically active when they are young. Their magnetic fields drive stellar winds, which rotationally slow-down the star by means of angular momentum transfer. The stellar spin-down over time is empirically quantified by the so-called “Skumanich-law“ as  $\omega \propto t^{-\frac{1}{2}}$  (Skumanich 1972). This relation, however, becomes invalid at very low masses. Among the field stars, it is observed that at the transition to fully convective stars at early M-type ( $\approx 0.3 M_\odot$ ), the rotational braking efficiency changes, and fast rotation ( $v_{\text{rot}} > 3$  km/s) becomes predominant (Delfosse et al. 1998; Mohanty & Basri 2003; Reiners & Basri 2008). The threshold between slow and rapid rotation is thought to be age-dependent (Hawley et al. 1999), so that young cluster stars are expected to show a rotation limit shifted towards higher masses or earlier spectral types, compared to (old) field stars.

Stellar rotation and magnetic activity are tightly linked by the underlying dynamo processes. In (young) clusters, it is observed that the fraction of active stars (eg. with chromospheric  $H_\alpha$  emission) sharply increases at different masses depending on the cluster age (“ $H_\alpha$  limit”, Hawley et al. 1999). At younger age, enhanced magnetic activity is seen at higher masses (ie. earlier spectral types) than it is for older clusters.

However, it is elusive whether this change in the locus of the  $H_\alpha$  limit is also due to an increase of the rapid rotation rate (Radick et al. 1987; Stauffer et al. 1987). Previous studies have focussed on the evolution of the  $H_\alpha$  limit in young and intermediate age clusters (Stauffer et al. 1997; Hawley et al. 1999; Reid et al. 1995) or field stars (West et al. 2004), but rotational velocities have only been measured extensively for field stars all across the main sequence (Delfosse et al. 1998; Mohanty & Basri 2003; West et al. 2008; Reiners & Basri 2008). However, for open clusters such as the Hyades,  $v_{rot} \sin i$  measurements have concentrated on earlier spectral types F to K (eg. Radick et al. 1987), and on the very low-mass regime (M-type and below; eg. Reid & Mahoney 2000), so that in the mid-K to early M-type range (hence in the range of the  $H_\alpha$ -limit) rotational velocities are scarce for the Hyades.

The present work addresses this scarcity between spectral classes K and M, and probes the coexistence of enhanced activity at the  $H_\alpha$  limit and rapid rotation for young stars in the case of the intermediate aged Hyades. We thus aim to determine if rapid rotation occurs at a different threshold in the Hyades with respect to field stars.

## 2. Sample selection and Observations

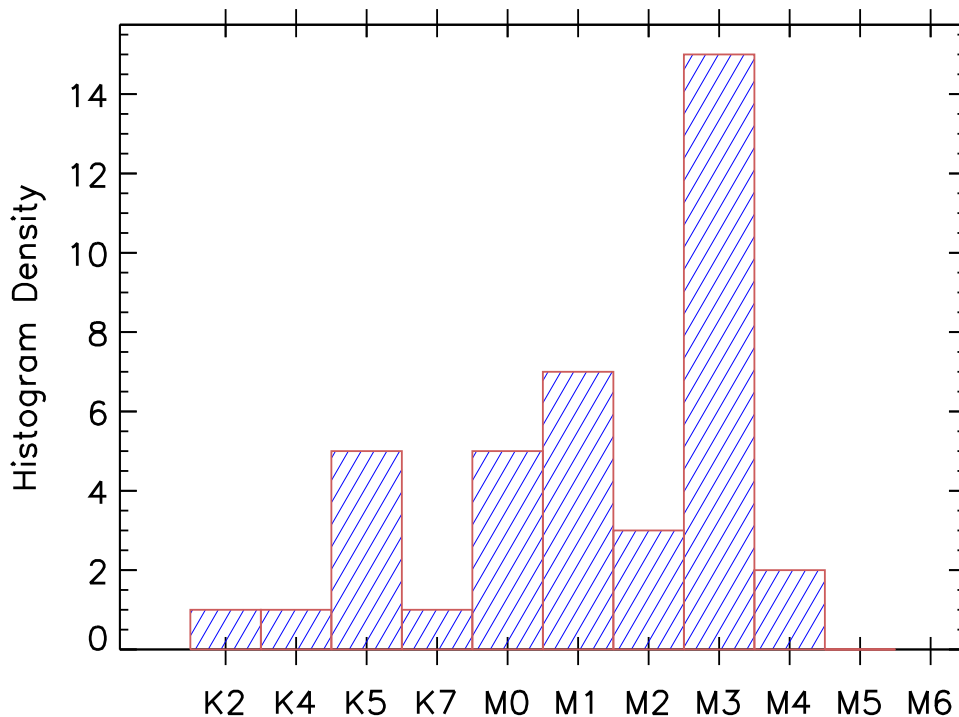


Figure 1. Distribution of spectral types in the Hyades sample. The total sample size is 40. The K-star bins are two spectral sub-types wide.

Our sample of low-mass stars comprises 40 members of the Hyades open cluster. Selection is based on color, and proper motions where available from the literature. All stars are drawn from spectral types early K to mid M, and thus bracket both sides of the  $H_\alpha$  limit observed for the Hyades. The age of the Hyades open cluster has been

estimated as  $625 \pm 50$  Myr (Perryman et al. 1998), so that also the later M-type members have already settled on the zero age main sequence and are expected to spin down.

We obtained high-resolution ( $R = 48\,000$ ) optical spectra between 360 nm and 920 nm for all our sample stars using the Fiber-fed Extended Range Optical Spectrograph (FEROS), mounted on the ESO/MPG 2.2 m telescope on La Silla. The signal-to-noise ratio exceeds 60 around 800 nm for the K-type objects. For the M-dwarfs, the SED falls off rapidly towards the blue, so that for these intrinsically faint objects ( $V = 12..15$ ) we still achieve a signal-to-noise ratio higher than 30 at 800 nm.

### 3. Data analysis

Data reduction of the echelle spectra follows standard procedures employing the FEROS pipeline package within MIDAS. From the extracted spectra,  $H_\alpha$  ( $\lambda 656.3$  nm) equivalent widths are measured as a proxy of chromospheric activity. We express the  $H_\alpha$  emission strength relative to the bolometric luminosity, ie.  $L_{H_\alpha}/L_{\text{bol}}$  to account for the steeply decreasing luminosity within the spectral range K–M, which would otherwise overestimate  $H_\alpha$  emission for earlier spectral types.  $L_{\text{bol}}$  is computed from synthetic Phoenix spectra (Hauschildt et al. 1999) of the same spectral type.

Rotational velocities  $v_{\text{rot}} \sin i$  are determined by a cross-correlation technique, similar to the methods used by Browning et al. (2010). For bins of adjacent spectral types, template spectra are constructed from slowly rotating stars of very similar spectral type as that of the sample stars. The template stars were also observed with FEROS to minimize the effects of instrumental profile, and have known  $v_{\text{rot}} \sin i < 2.5$  km/s, which is our detection limit. We consider their rotation as negligible. The templates are then artificially broadened employing a line-broadening kernel, and cross-correlated against the object spectra to construct a line broadening curve, from which  $v_{\text{rot}} \sin i$  is derived. Cross-correlation is performed in about 20 selected wavelength-ranges, typically 0.2 – 0.5 nm wide, between 500 – 900 nm that contain moderately deep, isolated photospheric lines. For each object,  $v_{\text{rot}} \sin i$  is derived from a set of template stars that bracket the object in spectral type.

Spectral classes of the sample objects are determined from the photometric  $H - K$  color (2MASS, Skrutskie et al. 2006), which gives a more reliable temperature indicator for the K and M-type stars than optical colors. The  $H$  and  $K$  magnitudes were also measured simultaneously, and hence are free of an activity bias that sequentially taken magnitudes might suffer from. The distribution of spectral types covered by the sample is shown in Fig. 1.

## 4. Results

### 4.1. Activity

From the 40 cluster stars, we find significant  $H_\alpha$  emission in 18 objects. Their normalized  $H_\alpha$  luminosity distribution is plotted in Fig. 2. All of the active stars we find within spectral range M0–M4. The strongest emission is detected at spectral type M3, in agreement with data from Reid & Mahoney (2000), who studied  $H_\alpha$  activity in a large sample of mostly M-type Hyades stars. The onset of activity in our data confirms an  $H_\alpha$  limit in the Hyades shifted to earlier spectral type when compared to field stars.

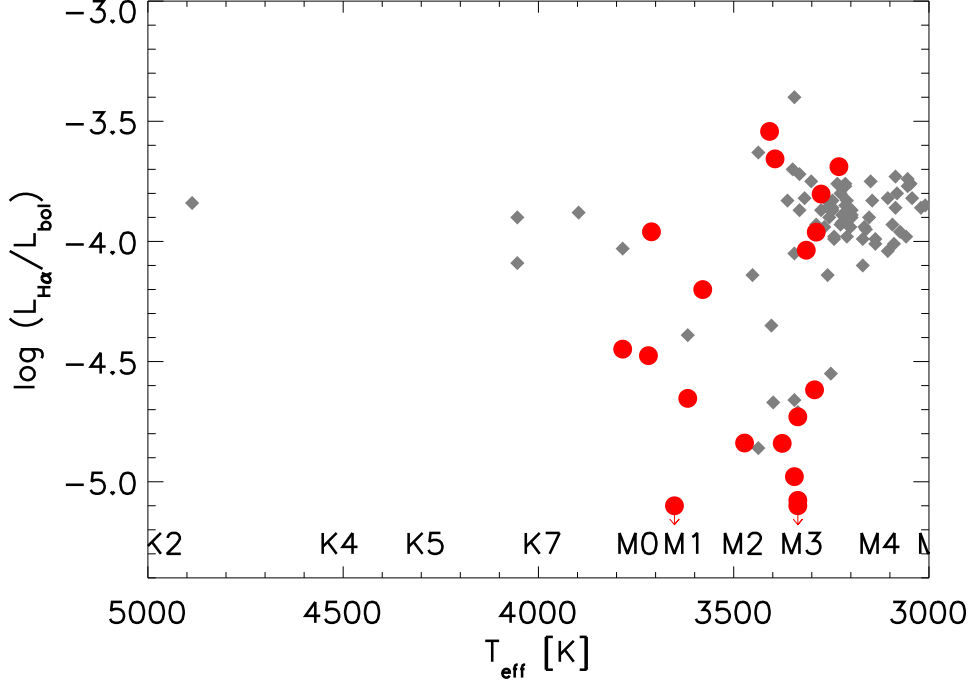


Figure 2. Normalized  $H_\alpha$  activity vs. spectral type for our sample Hyads (red points). Data from Reid & Mahoney (2000) is overplotted as diamonds. The combined data indicates that chromospheric magnetic activity ( $H_\alpha$  emission) for the Hyades arises at higher masses (M0–M2) than for (old) field stars ( $\approx$ M3). No predominant activity is seen in K-stars due to magnetic braking (slow rotators, cf. Fig. 3).

#### 4.2. Rotational velocities

We detect rotation above the detection limit of  $v_{rot} \sin i > 2.5$  km/s in 30 stars, spread over all spectral types in the sample. We find rapid rotation with  $v_{rot} \sin i > 10$  km/s among the M dwarfs, with an increase in  $v_{rot} \sin i$  towards higher rotation rates around M0, while we do not see any fast rotators ( $v_{rot} \sin i > 5$  km/s) among the K stars. The latter is likely due to the stronger rotational braking in the K-type regime. We find that the locus of the rotation limit at  $\approx$ M0 in the 625 Myr aged Hyades data is shifted to higher masses, compared to the rotation limit at spectral class  $\approx$ M3 found in old field stars (see Joshi et al, these proceedings).

Our findings in  $H_\alpha$  are in good agreement with previous chromospheric  $H_\alpha$  (Hawley & Reid 1994) and coronal activity measurements from X-rays (Fig. 5; Stern et al. 1995; Güdel 2004). In both activity proxies, a threshold in normalized activity luminosity is observed at spectral type  $\approx$ M0 in the Hyades. The behaviour in  $v_{rot} \sin i$  seems to coincide, suggesting that the rotation-activity relation known for field stars is still in place in a 625 Myr cluster (Fig. 4). This is also supported by recent photometric studies of the Hyades (see Delorme et al, these proceedings) that show a clear drop-off in rotational period at  $J - K_s \approx 0.85$  (spectral type M0).

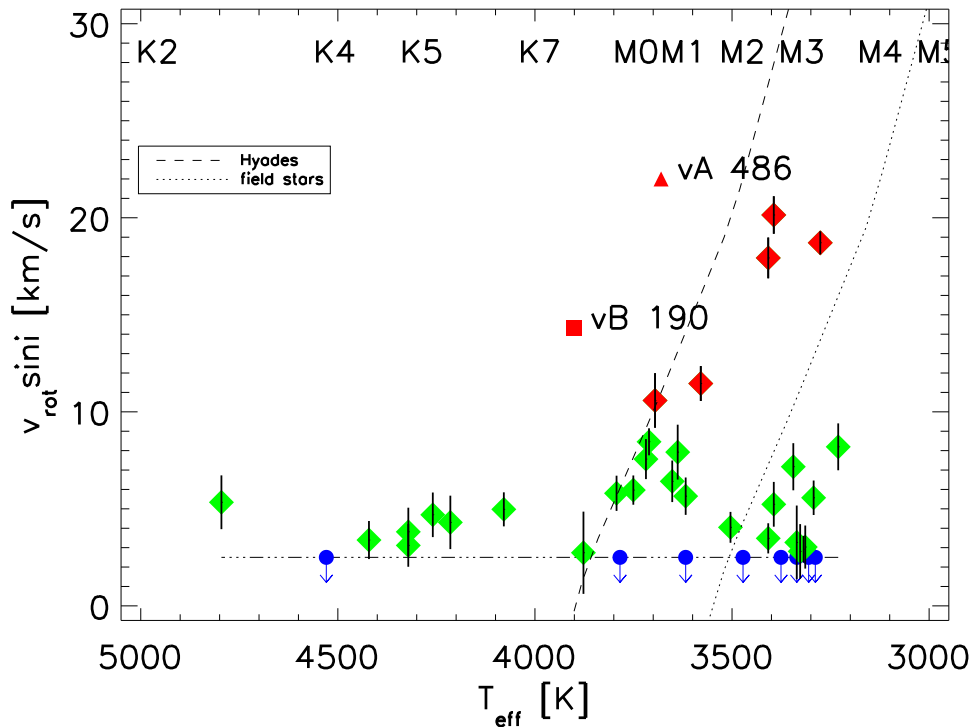


Figure 3. Measured rotational velocities  $v_{\text{rot}} \sin i$  as a function of temperature (with corresponding spectral types) for the Hyades sample. Non-detections (below our detection limit; blue points), rotators (green diamonds) and rapid rotators (red diamonds) indicate an increase in  $v_{\text{rot}} \sin i$  towards higher rotation rates in the Hyades around  $\approx M0$  (dashed line for illustration), in contrast to field stars where this threshold kicks in at  $\approx M3$  (dotted line). We thus see activity and rotation in the 625 Myr young Hyades at earlier spectral types than in old ( $\approx 5$  Gyr) field stars. VA486 (red triangle) from Seifahrt et al. (2009), vB190 (red square) from Radick et al. (1987).

## 5. Conclusions

Our sample of Hyads shows increased rotation alongside with  $H_\alpha$  activity at spectral types  $\approx M0$  and later. We see evidence that young, early M- type stars rotate faster than field stars do. This is possibly influenced by the different contraction timescales present in these young stars over this range of spectral types, giving rise to different braking efficiencies and histories.

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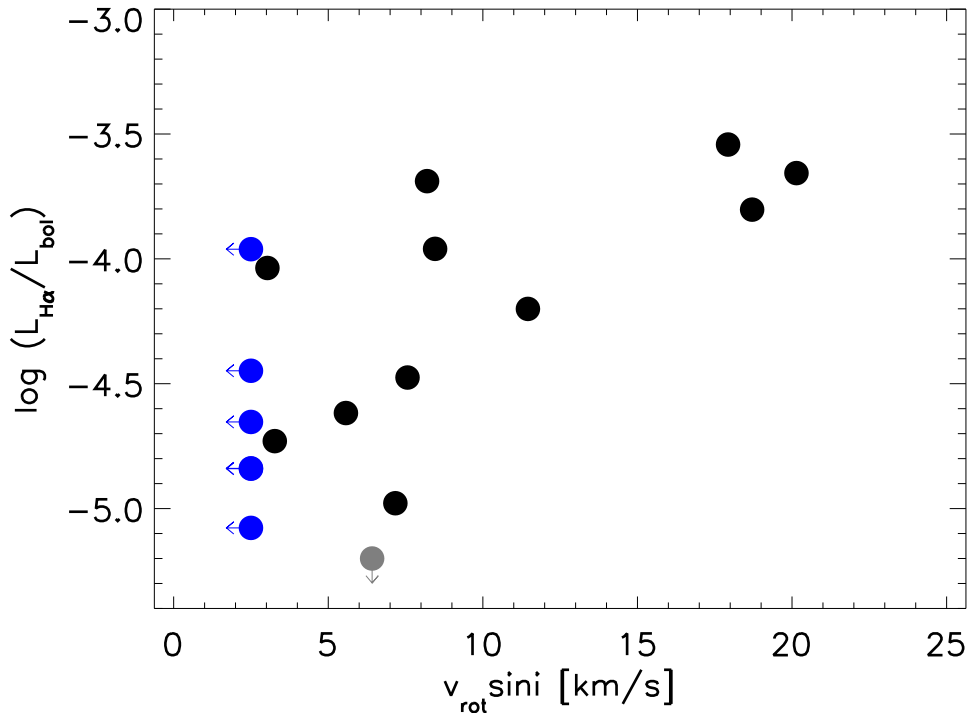


Figure 4. Normalized  $H_{\alpha}$  activity vs. measured  $v_{rot} \sin i$  for our sample Hyads (black points; gray and blue points mark upper limits in activity and rotational velocity, respectively). The most active objects are also the most rapid rotators, which is consistent with the rotation-activity relation seen in field stars.

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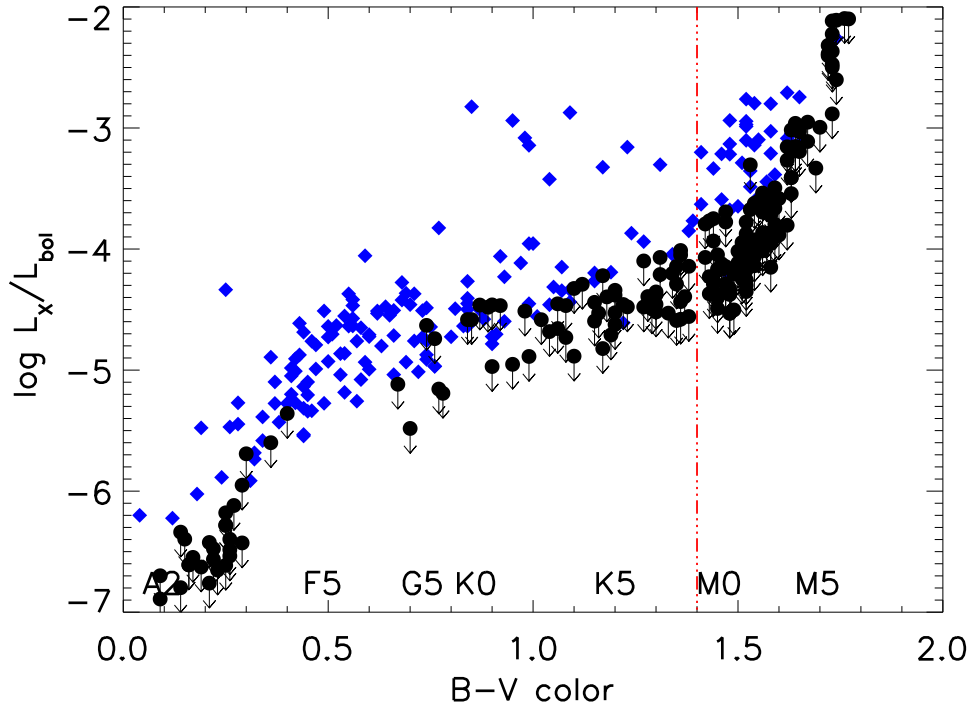


Figure 5. Normalized X-ray (ROSAT) luminosity as a function of (B-V) color (blue diamonds, upper limits as black points; with correspondence to spectral types) shows a strong increase in coronal activity at spectral type  $\approx M0$  (indicated by dashed line) for the Hyades, analogous to chromospheric activity. Data from the catalog in Stern et al. (1995).

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